

MAGNIFICATION CORRECTION EMPLOYING OUT-OF-PLANE DISTORTION OF A SUBSTRATE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims priority to U.S. provisional patent application number 60/433,477 filed on December 13, 2002, entitled "Method and System for Magnification and Distortion Control for Layer-to-Layer Alignment in Imprint Lithography," which is incorporated by reference herein.

BACKGROUND OF THE INVENTION

[0002] The field of invention relates generally to lithography systems. More particularly, the present invention is directed to control the relative dimensions of recorded patterns and original patterns during lithography processes.

[0003] Great interest surrounds magnification and reduction of pattern sizes during lithographic processes. As discussed by Feldman et al., in *WAFER CHUCK FOR MAGNIFICATION CORRECTION IN X-RAY LITHOGRAPHY*, J. Vac. Sci. Technol. B 16(6), Nov/Dec 1998 pp. 3476-3479, one method to correct magnification, involved bending a wafer to conform to a chuck surface, a portion of which is a sphere of adjustable radius. As a result, both increases and decreases in a pattern size may be accommodated by using convex and concave spherical surfaces.

[0004] United States patent application number 09/907,512 entitled *HIGH RESOLUTION OVERLAY ALIGNMENT METHODS & SYSTEM FOR IMPRINT LITHOGRAPHY*, filed July 16, 2001, discloses correction of magnification errors during imprint lithography processes. Specifically, disclosed is a template adjustment device that may be coupled to a support configured to hold the template during use. The template adjustment device may be configured to alter the size of the template during use. This may be achieved by

applying forces to, or altering the temperature of, the template. Similarly, the dimensions of the substrate may be altered, in lieu thereof or in conjunction therewith. In this manner, compensation of magnification errors may be achieved to ensure that a template or photolithographic mask used to pattern a layer is properly adjusted with an existing patterned layer disposed on the substrate.

[0005] A need exists, therefore, to provide improved control over relative dimensional sizes of an original pattern disposed on a mold and a recorded pattern on a substrate.

SUMMARY OF THE INVENTION

[0006] The present invention is directed to a method of controlling dimensional differences/similarities between an original pattern present in a mold and a recorded pattern present in a layer of a substrate. In this manner, the size of the recorded pattern may appear to be magnified and/or reduced, when compared to the original pattern. To that end, the method comprises defining a region on the layer in which to produce the recorded pattern. The substrate is bent to produce a contoured substrate surface in the region. Dimensional variations in the original pattern are produced by bending the mold, defining a varied pattern. The contoured surface and the mold are provided to have similar radii of curvatures. The varied pattern is then recorded in the layer. These and other embodiments of the present invention are discussed more fully below.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] Fig. 1 is a perspective view of a lithographic system in accordance with the present invention;

[0008] Fig. 2 is a simplified elevation view of a lithographic system shown in Fig. 1;

[0009] Fig. 3 is a simplified representation of material from which an imprinting layer, shown in Fig. 2, is comprised before being polymerized and cross-linked;

[0010] Fig. 4 is a simplified representation of cross-linked polymer material into which the material shown in Fig. 3 is transformed after being subjected to radiation;

[0011] Fig. 5 is a simplified elevation view of a mold spaced-apart from the imprinting layer, shown in Fig. 1, after patterning of the imprinting layer;

[0012] Fig. 6 is a simplified elevation view of an additional imprinting layer positioned atop of the substrate shown in Fig. 5, after the pattern in the first imprinting layer is transferred therein;

[0013] Fig. 7 is a top down view of a wafer, shown in Figs. 2, 5 and 6, upon which imprinting layers are disposed;

[0014] Fig. 8 is a detailed view of Fig. 7 showing the position of the mold in one of the imprint regions;

[0015] Fig. 9 is a simplified cross-sectional plan view of out-of-plane distortion of the template and wafer shown in Figs. 1 and 2;

[0016] Fig. 10 is a cross-sectional view of a template chucking system and a wafer chucking system in accordance with the present invention;

[0017] Fig. 11 is a flow diagram showing a method of controlling dimensional variations in patterns formed using imprint lithography techniques in accordance with the present invention; and

[0018] Fig. 12 is a flow diagram showing a method of controlling dimensional variations in patterns formed

using imprint lithography techniques in accordance with an alternate embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0019] Fig. 1 depicts a lithographic system 10 in accordance with one embodiment of the present invention that includes a pair of spaced-apart bridge supports 12 having a bridge 14 and a stage support 16 extending therebetween. Bridge 14 and stage support 16 are spaced-apart and typically formed from thermally stable materials, e.g., materials having a thermal expansion coefficient of less than about 10 ppm/degree centigrade at about room temperature (e.g. 25 degrees Centigrade). To that end, bridge supports 12, bridge 14, and/or stage support 16 may be fabricated from one or more of the following materials: silicon carbide, iron alloys available under the trade name INVAR[®], or name SUPER INVAR[™], ceramics, including but not limited to ZERODUR[®] ceramic. Coupled to bridge 14 is an imprint head 18, which extends from bridge 14 toward stage support 16. Disposed upon stage support 16 to face imprint head 18 is a motion stage 20. Motion stage 20 is configured to move with respect to stage support 16 along X and Y axes, but may move along the Z axis, as well. A radiation source 22 is coupled to system 10 to impinge actinic radiation upon motion stage 20. As shown, radiation source 22 is coupled to bridge 14 and includes a power generator 23 connected to radiation source 22. The components of system 10 are supported by table 24 that may be constructed to isolate the components of system 10 from vibrations in the surrounding environment. An exemplary table 24 is available from Newport Corporation of Irvine, California.

[0020] Referring to both Figs. 1 and 2, connected to imprint head 18 is a template 26 having a mold 28 thereon. Mold 28 includes a plurality of features defined by a plurality of spaced-apart recessions 28a and protrusions 28b. The plurality of features defines an original pattern that is to be transferred into a wafer 30 positioned on motion stage 20. To that end, imprint head 18 is adapted to move along the Z axis and vary a distance "d" between mold 28 and wafer 30, but may move along the X and Y axes, as well. In this manner, the features on mold 28 may be imprinted into a flowable region of wafer 30, discussed more fully below. Radiation source 22 is located so that mold 28 is positioned between radiation source 22 and wafer 30. As a result, mold 28 is fabricated from material that allows it to be substantially transparent to the radiation produced by radiation source 22.

[0021] Referring to both Figs. 2 and 3, a flowable region, such as an imprinting layer 34, is disposed on a portion of surface 32 that presents a substantially planar profile. Flowable region may be formed using any known technique such as a hot embossing process disclosed in United States patent number 5,772,905, which is incorporated by reference in its entirety herein, or a laser assisted direct imprinting (LADI) process of the type described by Chou et al. in Ultrafast and Direct Imprint of Nanostructures in Silicon, Nature, Col. 417, pp. 835-837, June 2002. In the present embodiment, however, flowable region consists of imprinting layer 34 being deposited as a plurality of spaced-apart discrete beads 36 of material 36a on wafer 30, discussed more fully below. Imprinting layer 34 is formed from a material 36a that may be selectively polymerized and

cross-linked to record the original pattern therein, defining a recorded pattern. Material 36a is shown in Fig. 4 as being cross-linked at points 36b, forming cross-linked polymer material 36c.

[0022] Referring to Figs. 2, 3 and 5, the pattern recorded in imprinting layer 34 is produced, in part, by mechanical contact with mold 28. To that end, imprint head 18 reduces the distance "d" to allow imprinting layer 34 to come into mechanical contact with mold 28, spreading beads 36 so as to form imprinting layer 34 with a contiguous formation of material 36a over surface 32. In one embodiment, distance "d" is reduced to allow sub-portions 34a of imprinting layer 34 to ingress into and fill recessions 28a.

[0023] To facilitate filling of recessions 28a, material 36a is provided with the requisite properties to completely fill recessions 28a while covering surface 32 with a contiguous formation of material 36a. In the present embodiment, sub-portions 34b of imprinting layer 34 in superimposition with protrusions 28b remain after the desired, usually minimum distance "d", has been reached, leaving sub-portions 34a with a thickness t_1 , and sub-portions 34b with a thickness, t_2 . Thicknesses " t_1 " and " t_2 " may be any thickness desired, dependent upon the application. For example, t_1 may be selected so as to be no greater than twice the width u of sub-portions 34a, i.e., $t_1 \leq 2u$, shown more clearly in Fig. 5, or thicknesses t_1 and t_2 may be established so that $|(t_1 - t_2)| \leq 2u$.

[0024] Referring to Figs. 2, 3 and 4, after a desired distance "d" has been reached, radiation source 22 produces actinic radiation that polymerizes and cross-links material 36a, forming cross-linked polymer material

36c. To that end, an exemplary radiation source 22 may produce ultraviolet radiation; however, other radiation sources may be employed, such as thermal, electromagnetic and the like. The selection of radiation employed to initiate the polymerization of the material in imprinting layer 34 is known to one skilled in the art and typically depends on the specific application which is desired. As a result of exposure to actinic radiation, the composition of imprinting layer 34 transforms from material 36a to material 36c, which is a solid. Specifically, material 36c is solidified to provide side 34c of imprinting layer 34 with a shape conforming to a shape of a surface 28c of mold 28, shown more clearly in Fig. 5. After imprinting layer 34 is transformed to consist of material 36c, shown in Fig. 4, imprint head 18, shown in Fig. 2, is moved to increase distance "d" so that mold 28 and imprinting layer 34 are spaced-apart. Additional processing may be employed to complete the patterning of wafer 30. For example, wafer 30 and imprinting layer 34 may be etched to transfer the pattern of imprinting layer 34 into wafer 30, providing a patterned surface 32a, shown in Fig. 6.

[0025] It is desired, that mold 28 have dimensions commensurate with the dimensions of a region of wafer 30 upon which the pattern is to be recorded to prevent distortions in the pattern recorded into imprinting layer 34. Specifically, distortions in the pattern recorded into imprinting layer 34 may arise from, *inter alia*, dimensional variations of imprinting layer 34 and wafer 30. These dimensional variations, which may be due in part to thermal fluctuations, as well as, inaccuracies in previous processing steps that produce what is commonly referred to as magnification/run-out errors. The

magnification/run-out errors occur when a region of wafer 30 in which the original pattern is to be recorded exceeds the area of the original pattern. Additionally, magnification/run-out errors may occur when the region of wafer 30, in which the original pattern is to be recorded, has an area smaller than the original pattern. The deleterious effects of magnification/run-out errors are exacerbated when forming multiple layers of imprinted patterns, shown as imprinting layer 124 in superimposition with patterned surface 32a, shown in Fig. 6. Proper alignment between two superimposed patterns is difficult in the face of magnification/run-out errors in both single-step full wafer imprinting and step-and-repeat imprinting processes.

[0026] Referring to Figs. 7 and 8, a step-and-repeat process includes defining a plurality of regions, shown as, a-1, on wafer 30 in which the original pattern on mold 28 will be recorded. The original pattern on mold 28 may be coextensive with the entire surface of mold 28, or simply located to a sub-portion thereof. The present invention will be discussed with respect to the original pattern being coextensive with the surface of mold 28 that faces wafer 30. Proper execution of a step-and-repeat process may include proper alignment of mold 28 with each of regions a-1. To that end, mold 28 includes alignment marks 114a, shown as a "+" sign. One or more of regions a-1 includes fiducial marks 110a. By ensuring that alignment marks 114a are properly aligned with fiducial marks 110a, proper alignment of mold 28 with one of regions a-1 in superimposition therewith is ensured. To that end, machine vision devices (not shown) may be employed to sense the relative alignment between alignment marks 114a and fiducial marks 110a. In the

present example, proper alignment is indicated upon alignment marks 114a being in superimposition with fiducial marks 110a. With the introduction of magnification/run-out errors, proper alignment becomes very difficult.

[0027] However, in accordance with one embodiment of the present invention, magnification/run-out errors are reduced, if not avoided, by creating relative dimensional variations between mold 28 and wafer 30. In this manner, the area of the original pattern is made coextensive with the area of the region a-1 in superimposition therewith.

[0028] The present invention attenuates, if not abrogates, magnification/run out errors by providing control of the relative dimensions between the original pattern and the region of wafer upon which the original pattern is to be recorded. Specifically, the present invention allows control of the dimensional relations between the original pattern present in mold 28 and the recorded pattern formed wafer 30. In this manner, the size of the recorded patterned may appear to be magnified and/or reduced, when compared to the original pattern. This may be achieved so that the sizes of the original pattern and the recorded pattern are equal.

[0029] Referring to Fig. 9, control of the relative dimensions between the original pattern and the recorded pattern is provided by bending of mold 28 and wafer 30, out the neutral, i.e., unbent, state. Consider that an area A of surface 32 may be defined as follows:

$$1. \quad A = \phi r$$

where r is a radius of a sphere about which surface 32 is curved and ϕ is the angle through which surface 32 is

bent. It is seen that changes in area dA may be defined as follows:

$$2. \quad dA = \phi \, dr$$

so that the change in area A may ultimately be defined as follows:

$$3. \quad dA = As/2r$$

where s is a thickness of wafer 30 measured between surface 32 and side 33. Thus, were surface 32 provided with a concave shape the area A is decreased, reduced. Conversely, were surface 32 provided with a convex shape the area A is increased, magnified. In a similar fashion, bending of template 26 results in dimensional changes in mold 28 in accordance with equations 1-3, and, hence, the pattern on mold 28 may be magnified or reduced.

[0030] Referring to Figs. 4 and 9, employing the concepts set forth above, compensation for magnification/run out errors is achieved by bending both template 26 and wafer 30. In this manner it is possible to obtain a desired amount of relative dimensional variations between a pattern on mold 28 and the region upon wafer 30 where the original pattern is to be recorded. For example, to magnify the original pattern on mold 28, template 26 would be bent so that surface 28c forms a convex shape. Surface 32 of wafer 30 would be bent to form a concave shape. Material 36a disposed between mold 28 and wafer 30 would then be solidified and polymerized, as discussed above, to form material 36c. Thereafter, mold 28 and wafer 30 would be returned to a

neutral, unbent, state. The net result is that recorded pattern would be magnified when compared with the original pattern of mold 28. The bending of both mold 28 and substrate 30 contribute to the magnification of the recorded pattern. Specifically, the magnification provided by wafer 30 resulted from wafer 30 returning to the neutral state. The magnification provided by mold 28 results from the expansion of the recorded pattern by bending of template 26 from the neutral state. In this fashion, it can be said that magnification is a function of the out-of-plane distortion applied to the original pattern. The dominant contributor to the magnification of the recorded pattern is defined by the relative distances s of wafer 30 and template 26. Specifically, the greater the s , the greater the contribution to the magnification in recorded pattern. Often, however, it is desired to minimize the out-of-plane distortion when achieving a desired magnification. To that end, for a given magnification requirement, it would be desirable to increase the distance of either template 26, wafer 30 or both. It has been found preferable to increase the distance of template 26, as the distance of wafer is typically standardized.

[0031] Another characteristic that is desirable to obtain from out-of-plane distortion is uniform dimensional variations over area A. To that end, it has been found beneficial to ensure minimization of the shear force to which mold 28 and/or the region of wafer 30 in which a pattern is to be recorded is subjected. It is desired that this shear force is zero. This allows obtaining uniform bending of mold 28 and/or the region of wafer 30 in which the pattern is to be recorded.

[0032] Referring to Fig. 10, an apparatus to obtain uniform bending of template 26 and wafer 30 is shown as a template chucking system 40 and a wafer chucking system 140. Template chucking system 40 includes a chuck body 42 adapted to retain template 26 employing vacuum techniques. To that end, chuck body 42 includes first 46 and second 48 opposed sides. A side, or edge, surface 50 extends between first side 46 and second side 48. First side 46 includes a first recess 52 and a second recess 54, spaced-apart from first recess 52, defining first 58 and second 60 spaced-apart support regions. First support region 58 cinctures second support region 60 and the first 52 and second 54 recesses. Second support region 60 cinctures second recess 54. A portion 62 of chuck body 42 in superimposition with second recess 54 is transparent to radiation having a predetermined wavelength, such as the wavelength of the actinic radiation mentioned above. To that end, portion 62 is made from a thin layer of transparent material, such as glass. However, the material from which portion 62 is made may depend upon the wavelength of radiation produced by radiation source 22, shown in Fig. 2. Portion 62 extends from second side 48 and terminates proximate to second recess 54 and should define an area at least as large as an area of mold 28 so that mold 28 is in superimposition therewith. Formed in chuck body 42 are one or more throughways, shown as 64 and 66. One of the throughways, such as throughway 64 places first recess 52 in fluid communication with surface 50. The remaining throughway, such as throughway 66, places second recess 54 in fluid communication with surface 50.

[0033] It should be understood that throughway 64 may extend between second side 48 and first recess 52, as

well. Similarly, throughway 66 may extend between second side 48 and second recess 54. What is desired is that throughways 64 and 66 facilitate placing recesses 52 and 54, respectively, in fluid communication with a pressure control system, such a pump system 70.

[0034] Pump system 70 may include one or more pumps to control the pressure proximate to recesses 52 and 54, independently of one another. Specifically, when mounted to chuck body 42, template 26 rests against first 58 and second 60 support regions, covering first 52 and second 54 recesses. First recess 52 and a portion 44a of template 26 in superimposition therewith define a first chamber 52a. Second recess 54 and a portion 44b of template 26 in superimposition therewith define a second chamber 54a. Pump system 70 operates to control a pressure in first 52a and second 54a chambers.

Specifically, the pressure is established in first chamber 52a to maintain the position of the template 26 with the chuck body 42 and reduce, if not avoid, separation of template 26 from chuck body 42 under force of gravity. The pressure in the second chamber 54a may differ from the pressure in the first chamber 52a to, *inter alia*, reduce distortions in the template 26 that occur during imprinting, by modulating a shape of template 26. For example, pump system 70 may apply a positive pressure in chamber 54a to compensate for any upward force R that occurs as a result of imprinting layer 34, shown in Fig. 5, contacting mold 28. For example, pump system 70 may apply a positive pressure in chamber 54a to compensate for any upward force R that occurs as a result of imprinting layer 34, shown in Fig. 5, contacting mold 28. In this manner, produced is a pressure differential between differing regions of side

46 so that bowing of template 26 and, therefore, mold 28 under force R is attenuated, if not avoided.

[0035] To provide out-of-plane distortion correction, chucking system 40 includes a shaping device 71 having a plurality of rigid pillars 72 each of which is positioned between two spaced-apart bladders 73a and 73b. Each pillar 72-bladders 73a and 73b combination defines a bending device. Although two bending devices are shown being spaced-apart, additional bending devices are usually present. Positioned between bending devices is a cavity 74 that is surrounded by a support 75. Chuck body 42 rests against support 75. A chamber is defined by cavity 74 and chuck body 42. The chamber is in fluid communication with pump system 70 via a conduit 76. Chuck body 42 is held firmly against shaping device 71 by evacuating the chamber defined by cavity 74 and chuck body 42. A portion 77 of shaping device 71 in superimposition with portion 62 is transparent to actinic radiation.

[0036] Out of plane distortion is achieved by selectively activating bladders 73a and 73b, thereby causing body of bending device to pivot about pillars. For example, were it desired to provide mold 28 with a convex surface, bladders 73b would be expanded. This would cause the body of shaping device 71 to bend such that central regions would move along the Z-axis toward chuck body 42. The bending motion of the body of shaping device 71 would then be transferred to chuck body 42 and, therefore, template 26. The longitudinal strain of bending of template 26 would then be transferred to mold 28 to achieve desired dimensional changes in the original pattern present thereon. In this example, magnification.

[0037] Were it desired to provide mold 28 with a concave surface, bladders 73a would be expanded. This would cause the body of shaping device 71 to bend such that central regions would move along the Z-axis away from chuck body 42. The bending motion of the body of shaping device 71 would then be transferred to chuck body 42 and, therefore, template 26. The longitudinal strain of bending of template 26 would then be transferred to mold 28 to achieve desired dimensional changes in the original pattern present thereon. In this example, reduction.

[0038] Employing a similar device, out-of plane distortion of wafer 30 could be achieved. To that end, a shaping device 71 would be included with wafer chucking system 140. Wafer chucking system 140 could be substantially identical to template chucking system 40, excepting that portion 62 may be obviated, were no actinic radiation to be transmitted therethrough. In this fashion, wafer 30 may be bent in a manner substantially similar to the bending of template 26.

[0039] Referring to Figs. 5 and 11, in operation, a region on wafer 30 is defined in which to produce a recorded pattern by depositing beads 36 at step 100. At step 102, wafer 30 is bent to produce a contoured surface in the region. At step 104, contact is made between template 26 and the region on wafer 30 by having mold 28 contact beads 36. At step 106, dimensional variations in the original pattern of mold 28 are undertaken by bending the template 26. In this manner, material 36a, shown in Fig. 4, in droplets conform to surface 28c of mold 28. At step 108, material 36c is formed, solidifying a pattern that is the inverse of the pattern in mold, forming a recorded pattern. Thereafter, the mold 28 is

material 36c, shown in Fig. 4, are separated and wafer 30 is returned to the neutral state at step 110. In this manner, the recorded pattern is the inverse of the original pattern in mold 28 with differing relative dimensional variations, i.e., magnified or reduced.

[0040] Referring to Figs. 5 and 12, in operation, a region on wafer 30 is defined in which to produce a recorded pattern by depositing beads 36 at step 200. At step 202, contact is made between template 26 and the region on wafer 30 by having mold 28 contact beads 36. At step 204, after contact with beads by mold 28, wafer 30 and template 26 are concurrently bent to produce a contoured surface in the region and an arcuate surface on mold 28. At step 206, material 36c, shown in Fig. 4, is formed, solidifying a pattern that is the inverse of the pattern in mold 28, forming a recorded pattern. At step 208, the wafer is returned to the neutral state. Thereafter, the mold 28 and material 36c, shown in Fig. 4, are separated and wafer 30 is returned to the neutral state at step 210. In this manner, the recorded pattern is the inverse of the original pattern in mold 28 with differing relative dimensional variations, i.e., magnified or reduced.

[0041] The embodiments of the present invention described above are exemplary. Many changes and modifications may be made to the disclosure recited above, while remaining within the scope of the invention. Therefore, the scope of the invention should be limited by the above description, but instead should be determined by the appended claims along with their full scope of equivalents.